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An Overview of 200kW Solar Power Plant Based on Organic Rankine Cycle

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Abstract

Solar-driven ORC-based distributed energy system (DES) is a potential integration energy solution for sustainable development of low carbon community. A 200kW ORC DES system was demonstrated in Tianjin for a combined supply of power, heating, cooling and fresh water from solar thermal energy source. This paper briefly introduced the information about the design and construction of this demonstration project. The main components in 200kW solar-driven multi-generation system are presented.

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Keywords: Organic Rankine cycle (ORC); solar energy; renewable energy; solar power; multi-generation

1. Introduction

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Solar energy is one of the most promising energy sources since the characteristics of sustainability and cleanliness. Solar ORC uses organic fluids as working fluids and solar energy as heat source. Through general researches, it is regarded as an effective method to convert solar radiation to electricity [1-3]. Hung [4] has made the comparison among benzene, toluene, p-xylene, R113 and R123, and the results indicate that the irreversible loss is minimum using p-xylene with heat source of 300ºC or so, but R123 and R113 are better with heat source of 200 ºC.

The reviewed information has shown that the solar ORC system is a promising technology for distributed electricity supply in the future with cascade utilization of energy for heating and cooling. However there is few experimental work in literature about large-scale solar ORC systems.

This paper aims to present a work about a 200kW solar-driven ORC multi-generation system using parabolic trough collectors which is still in progress. The system is located in Binhai New District, Tianjin, China. Now most of the components of this plant have been installed. Due to page limitation, only core system on solar ORC is presented in this paper.

Nomenclature

ORC	Organic Rankine Cycle
DES	Distributed energy system
T	Temperature
P	Pressure
ρ	Density
h	Enthalpy
s	Entropy

2. Solar ORC power plant

2.1. Outline

Fig. 1. Full view of the solar power plant

This solar power plant can provide electricity, heating and cooling for the buildings nearby and it is the first experimental platform possessing parabolic trough collectors of more than 1000m^2 in China. Figure 1 shows a full view of the solar power plant. The two arrays are parabolic trough collectors and each one is 100m in length. The left building is an equipment room for the absorption chiller with 120kW refrigerating capacity, and its working fluid is LiBr/water. The middle building is a room for components of ORC system which includes pumps, evaporators, turbine, condensers, storage tank, pipelines, valves, equipment for measurement and so on. The right building is the room for oil-side system which includes pumps, boiler, heat exchanger for heating, lower storage tank, upper level-pressure tank and so forth. The small building at the bottom of right corner is the room for a storage tank of diesel oil for boiler. Figure 2 is the schematic diagram of the solar power plant. The whole system can be divided into four parts: ORC system, oil-side system, refrigeration system and district heating system.

2.2. ORC system

The ORC system is the vital part for power generation of DES and the main components of the system are working fluid, working fluid pump, heat exchangers, turbine, storage tank and cooling tower. The designed efficiency of ORC system is 10% and the objective of output power is 200kW. The process of selecting working fluid and other components are described as follows.

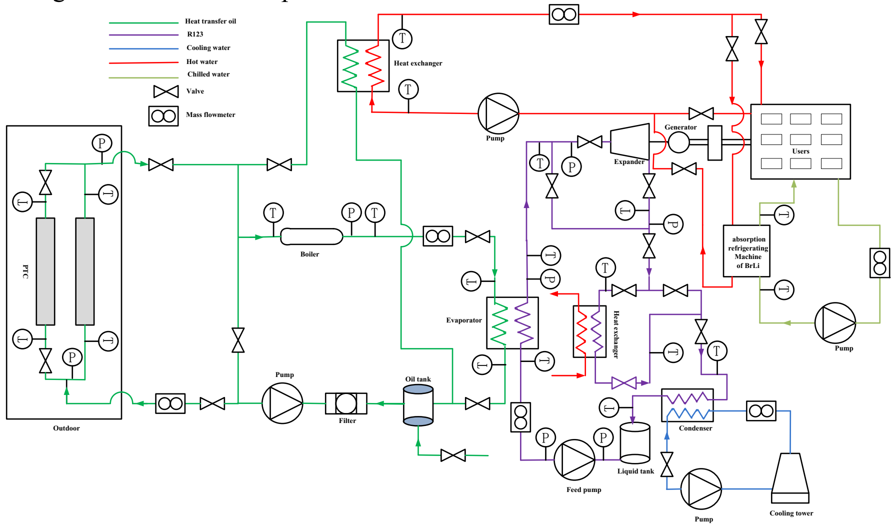

Fig. 2. Schematic of the solar power plant

2.2.1. Working fluid of ORC

The selection of working fluid is based on some criteria, such as thermo-physical properties, ozone depletion potential, global warming potential, safety and the price. Additionally, it is better to use working fluids under their critical pressure and critical temperature because the heat transfer and flowing characteristics are complicated above critical point. Few organic working fluids have satisfying performance above 150 ºC. Then after a comparison among R123, R134a, R141b and several other kinds of fluids, R123 is finally selected as the working fluid of the ORC in the power plant. The charging of working fluid into pipes and heat exchangers etc. has been finished already, and the total amount of usage is 4500 kg.

2.2.2. Design operating condition of ORC

Based on the thermo-physical properties of chosen working fluid, the operating condition of the ORC system is designed. After theoretical calculations, each operating point is confirmed and those points are schematically shown on T-S diagram.

Table 1. Design points of the ORC

Point	T ºC	P MPa	ρ kg/m^3	h kJ/kg	s kJ/（kg·K）
1	52	1.5	1402.7	251.4	1.169
2	131	1.5	1127.1	343.2	1.422
3	131	1.5	94.4	459.6	1.70
4	145	1.5	86.2	468.2	1.730
5	78	0.2	11.1	432.79	1.734
6	48	0.2	12.3	410.3	1.667
7	48	0.2	1403.1	249	1.164
8	50	0.2	12.2	411.79	1.67

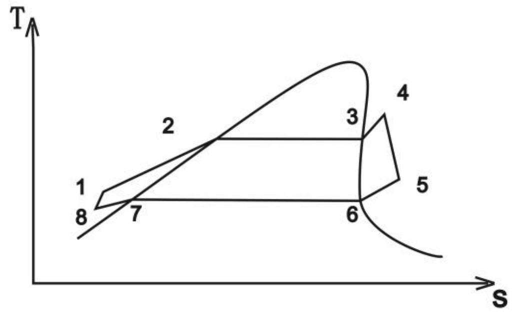

Fig. 3. Temperature-entropy diagram of the ORC

Flow rate of R123 is set to 10kg/s for 200kW output power. Based on these data, we can design the oil-side system to control the temperature and flow rate of oil.

2.2.3. Pump

A modified centrifugal pump called canned-motor pump is selected. The greatest advantage of this kind of pump is that the motor and the fluid are separated to prevent leak out, and this feature is very helpful when some poisonous or inflammable fluids are used. This pump is produced by Dalian Huanyou Canned Pump co., LTD and the power consumption is 45kW. The rated capacity and head of delivery are $27m^3/h$ and 160m, respectively. Figure 4 shows the pump and the evaporators with insulating layers.

Fig. 4. Working fluid pump and heat exchangers

2.2.4. Heat exchangers

The heat exchangers used in this system are all countercurrent flow shell-tube heat exchangers and the working fluid of R123 is in the shell side while heat transfer oil is in the tube side. There are three heat exchangers used as the evaporator and the total heat transfer area of evaporator is $174m^2$, and the flux of heat exchange is 2.1MW. The length of one of these three heat exchangers is 3.8m and the diameter is 0.63m.

2.2.5. Storage tank

Fig. 5. Storage tank and oil pump

The storage tank is used to filter the vapor within the condensate and provide a pressure head for the working fluid pump to prevent the occurrence of cavitation from hurting the fans of the pump. Figure 5 is the storage tank with insulating layers with the volume of approximately 3 m^3 and the oil pump.

2.3. Oil-side system

The oil-side system provides the heat source for the ORC system. The oil firstly goes through the parabolic trough collectors to gain available solar energy, and then goes through the auxiliary boiler to get high temperature for the ORC system, and then goes through the evaporators to produce the vapor of R123 for turbine, and then goes back to the vapor-liquid separation equipment, and then goes to the inlet of the oil pump. The designed temperature of the oil at the outlet of the boiler is 200 ^oC, but the boiler can provide oil with higher temperature to 330 ^oC.

2.3.1. Heat transfer oil

The heat transfer oil must have the good stability and low carbonization under high temperature, good flowing ability under low temperature. The components of oil-side system cannot be started if the viscosity of oil is too large in winter. Additionally, according to the weather data of Tianjin, the oil cannot be frozen under the conditions of ambient temperature above -20 ^oC to ensure the safety of equipment. The heat transfer oil named Therminol 55 produced by Solutia Inc. is selected finally, and the total amount of usage is 8000 kg.

2.3.2. Oil pump

Through the hydraulic calculations and consideration of safety, we also choose a canned-motor pump which is produced by Shanghai Nikkiso Non-seal Pump Co, and the power consumption is 22kW. The rated capacity and head of delivery are 38m^3/h and 80m, respectively.

2.3.3. Boiler

The boiler is a complementary component for area shortage of parabolic trough collectors. This may not match the “solar power plant” well but that is what we can do to test a 200kW-grade ORC system without enough investment. The rated output power of this boiler is 2.4MW and the fuel is diesel oil. Figure 6 is the boiler and the solar collectors, and the red part is the burner of the boiler.

2.3.4. Parabolic trough collectors

Until now the area of the installed parabolic trough collectors is 1096 m^2, and the purchase and installation of solar collectors have cost 1,800,000 CNY. If it is changed to that all the heat for the ORC system is from the solar field, we have to install 10000 m^2 more solar collectors. When the solar collector arrays become more, more pump, oil, pipes, valves and control equipment etc. are needed which means a huge investment is in demand. Additionally, the complexity will increase rapidly with more components. So we expect to do some preliminary work of this kind of solar power plant, we may add more solar collectors in the solar power plant for further researches in the future.

The parabolic trough collectors used here are provided by Himin Solar co. and some detailed information is presented in table 2.

Fig. 6. Boiler and Parabolic trough collectors

Table 2. Parameters of mirrors and tubes

Parameters	Values
Width of the aperture	5.76m
Focal distance of trough	1.71m
Reflectivity of mirrors	≥93%
Internal mirror size	1700mm×1641mm
External mirror size	1700mm×1501mm
Numbers of mirrors for standard unit	7 internals, 7externals
Length of standard unit	12m
Concentration ratio	80
Length of tube	4060mm
Diameter of external glass tube	120mm
Diameter of internal metal tube	70mm
Heat loss at 400 ºC	<230W/ m^2
Film absorptivity	≥95%
Optical efficiency	≥78%
Thermal efficiency at 400 ºC	57.5%

Acknowledgements

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